The impact of the assimilation of ozone from the Tropospheric Emission Spectrometer on surface ozone across North America

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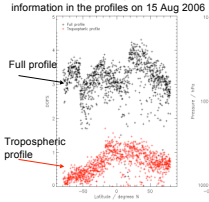
Abstract. We examine the potential of ozone data retrieved from the Tropospheric Emission Spectrometer (TES) for constraining background ozone values across North America in the GEOS-Chem chemical transport model. We assess here how changes in the abundance of background ozone in the free troposphere, following assimilation of TES data, impacts the surface ozone distribution in August 2006. We show that the assimilation increases the model surface ozone across the continent, with small changes of less than 3 ppbv in the eastern United States and larger changes of up to 9 ppbv over the western United States. This represents an increase of 15-25% of background ozone over the west coast and across Canada. We find that despite the good agreement between the assimilated ozone distribution and the ozonedonde measurements in the free troposphere, comparisons with surface measurements from the EPA AQS and Environment Canada NAPS networks show that the assimilation exacerbates the bias in surface ozone in the model, suggesting potential model errors in the ozone precursor emissions or in the downward transport of ozone into the boundary layer in the model. Our results suggests that combining TES data with observations of ozone precursors, such as NO_2 and HCHO, will enable us to more effectively isolate the impact on surface ozone abundances of discrepancies in local precursor emissions or in the description of transport into the boundary layer.

1. TES Instrument

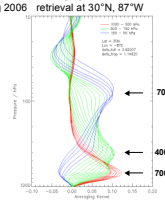
- One of four instruments on the NASA EOS Aura spacecraft (launched July 15, 2004)
- Infrared Fourier transform spectrometer (3.3 - 15.4 μm)
- Nadir footprint = 8 km x 5 km
- Orbit repeats every 16 days
- Observations spaced about 2º along the orbit track
- Data products include O_3, CO, H_2O, HDO, and temperature

TES retrievals provide a smoothed representation of the true state

Number of independent pieces of information in the profiles on 15 Aug 2006



Averaging kernels for retrieval at 30°N, 87°W



Total DOFS = 3.92 and tropospheric DOFS=1.15, with maximum sensitivity at 700 hPa, 400, and 70-90 hPa

2. Chemical Data Assimilation Methodology

Sequential sub-optimal Kalman filter: $\hat{\mathbf{x}}^a = \mathbf{x}^f + \mathbf{K}[\mathbf{y}^{obs} - \mathbf{H}\mathbf{x}^f]$

Kalman Gain Matrix: $\mathbf{K} = \mathbf{P}^f\mathbf{H}^T(\mathbf{H}\mathbf{P}^f\mathbf{H}^T + \mathbf{R})^{-1}$

Analysis Error Cov. Matrix: $\mathbf{P}^a = (\mathbf{I} - \mathbf{K}\mathbf{H})\mathbf{P}^f$

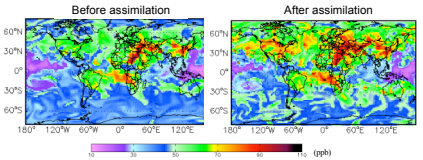
- Observation operator ($\mathbf{H}$) accounts for TES averaging kernels and a priori profiles
- Analysis error variance transported as a passive tracer
- O_3 and CO profile retrievals from TES
- 6-hour analysis cycle
- Assumed forecast error of 50% for CO and O_3
- Neglected horizontal correlations in forecast and observation error covariance matrices

3. The GEOS-Chem Model

- Chemical transport model
- 2.0° latitude x 2.5° longitude, 55 vertical levels (top level approx. 0.01 hPa)
- O_3-NOx-hydrocarbon chemistry
- Linearized (LINOZ) O_3 chemistry in the stratosphere
- Model transport driven by assimilated meteorological fields (GEOS-4) from NASA GMAO

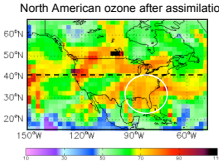
4. Impact of Assimilation on Free Tropospheric Ozone

Monthly mean ozone at 5 km for August 2006



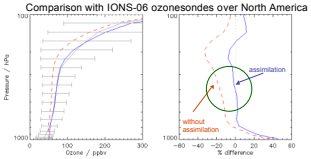
Assimilation of TES data (1 July - 31 August 2006) increased significantly ozone in the free troposphere, across the northern hemisphere in the model

North American ozone after assimilation



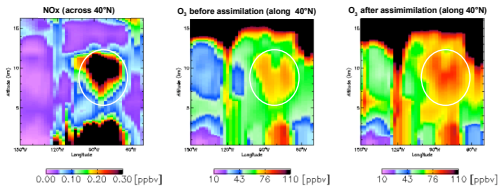
The summertime ozone maximum over the southeast is more pronounced after assimilation

Comparison with IONS-06 ozonesondes over North America



Significant improvement in tropospheric ozone (down to 800 hPa) following assimilation.

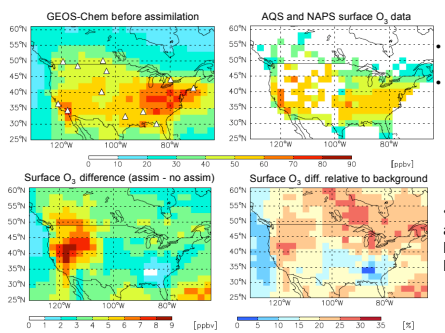
Assimilation increased upper tropospheric ozone over the southeast (30°– 40°N, 80°–100°W) by 11 ppb, in agreement with previous estimates of 10-13 ppb by Cooper et al. [2006] and Hudman et al. [2007] for the enhancement in upper troposphere ozone due to lightning NOx.



[Parrington et al. (2008a), Estimating the summertime tropospheric ozone distribution over North America through assimilation of observations from the Tropospheric Emission Spectrometer, *J. Geophys. Res.*, doi:10.1029/2007JD009341]

5. Impact of Assimilation on Surface Ozone

Mean surface ozone (12h - 18h local time) for August 2006



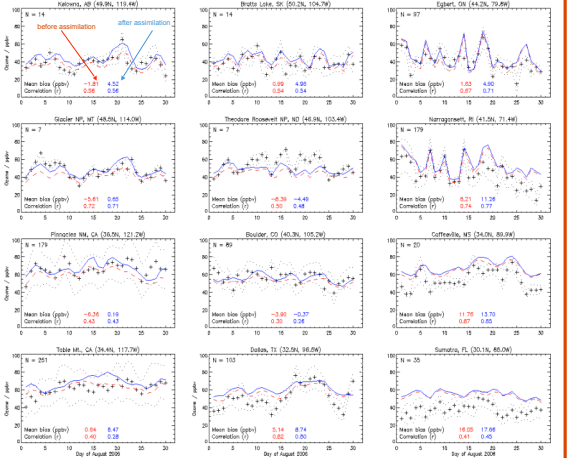
- The model overestimates surface ozone in the east and underestimates it in the west
- Surface data from US Environmental Protection Agency Air Quality System (AQS) and the Environment Canada National Air Pollution Surveillance (NAPS) network, binned on the 2°x2.5° GEOS-Chem grid

•Increased free tropospheric ozone in the assimilation enhances the downward flux of background ozone into the North American boundary layer in the model

Surface ozone abundances in the assimilation increased by as much as 9 ppb, with the largest increase in western North America and the smallest increase in the southeastern USA.

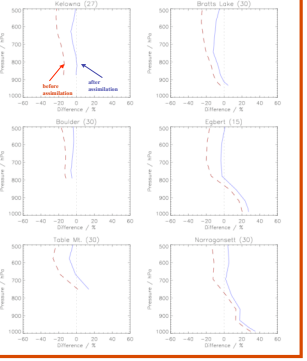
6. Comparison with AQS and NAPS Ozone Data

The model before assimilation is shown in red, whereas the model after assimilation is in blue. Surface data are shown indicated by the + symbols



Assimilation reduced the bias in the western sites (which are influenced mainly by background ozone) and increased it in the east

Comparison with ozonesondes (August 2006)



The larger impact in the west is due, in part, to the higher elevation and deeper mixing layer in the west [e.g. Fiore et al. 2002; Dougherty 2008]

[Parrington et al. (2008b), The impact of the assimilation of ozone from the Tropospheric Emission Spectrometer on surface ozone across North America, *Geophys. Res. Lett.*, submitted.]

7. Conclusions

- Assimilation of TES data reduced the bias in free tropospheric O_3 in the model from -35% to less than 5% (down to about 800 hPa)
- The improved distribution of O_3 in the free troposphere produced an increase in O_3 in the boundary layer of as much as 9 ppb (mainly in western North America)
- Increased background O_3 in the assimilation reduced the model bias in surface O_3 in western North America, but increased it in the east
- The increase in the bias in surface O_3 despite the improvement in free tropospheric O_3 indicates the presence of errors in the surface sources or sinks of O_3 or in the vertical transport of O_3 into the boundary layer in the model